The Kinetic Flux of Quasar Jets

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6. Jet Propulsion Laboratory

Summary

X-Ray Observations Provide Evidence that Radio Jets:

1. **Carry Large Flux of Energy – Greater than Accretion Luminosity**

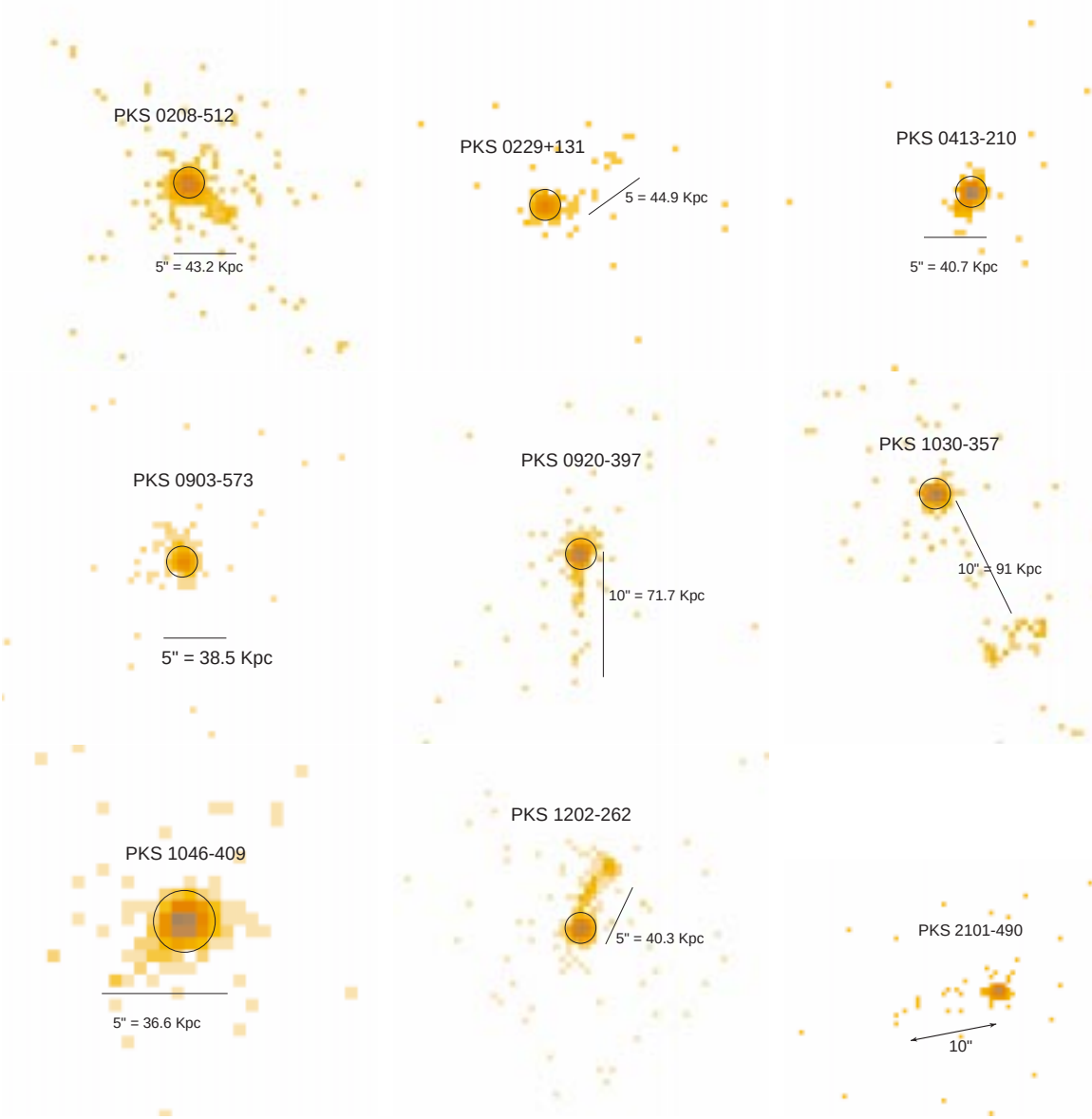
2. **Transport Energy Very Efficiently – $L_{jet} / K_{jet} \lesssim 10^{-5}$**

We Predict:

3. **X-ray Jets become more prominent at large redshift**

Outline

1. **X-Ray Observations of Radio Jets**
2. **Spatially Resolved Analysis**
3. **Spectral Energy Distribution**
4. **Interpretation as IC/CMB**
5. **The Kinetic Power**



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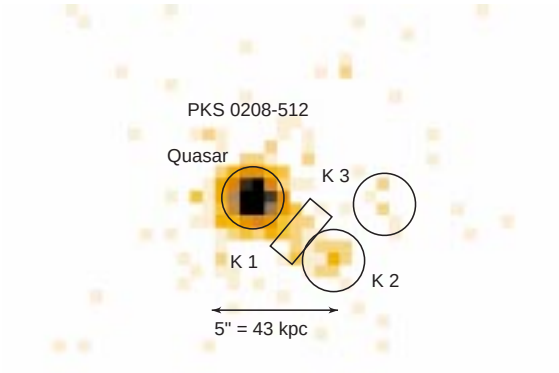

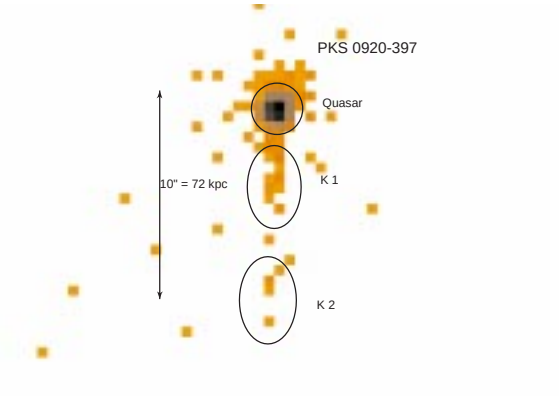

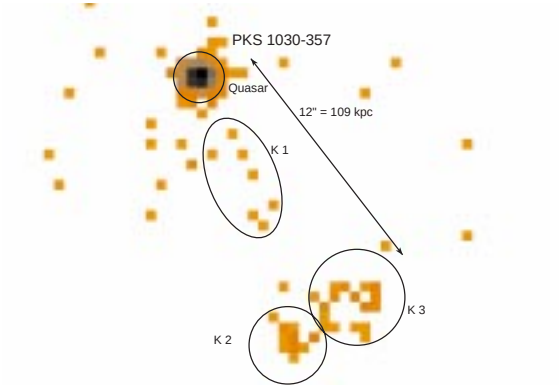

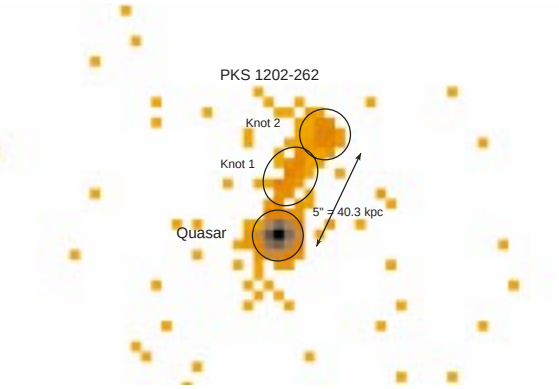

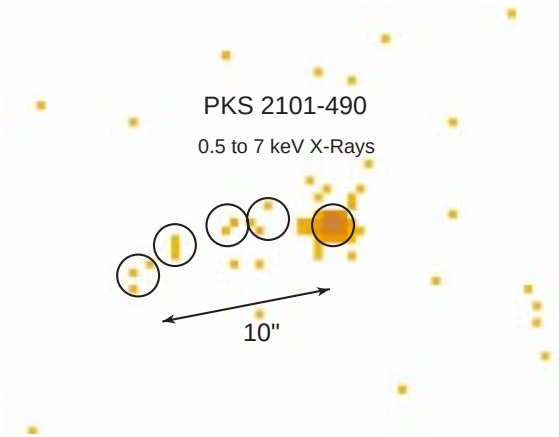

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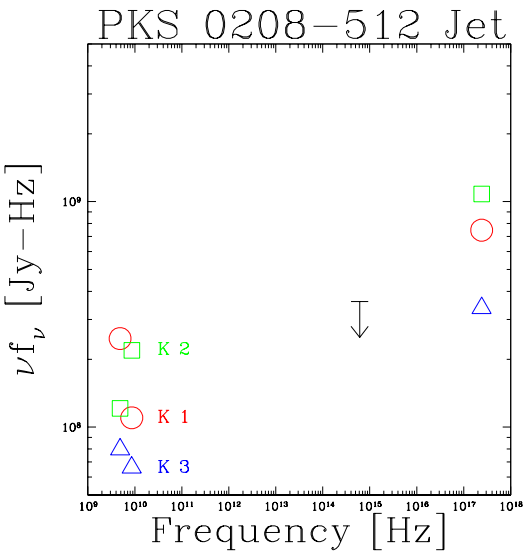

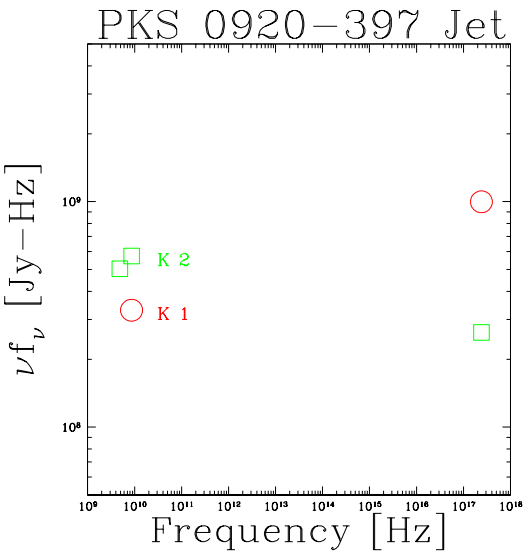

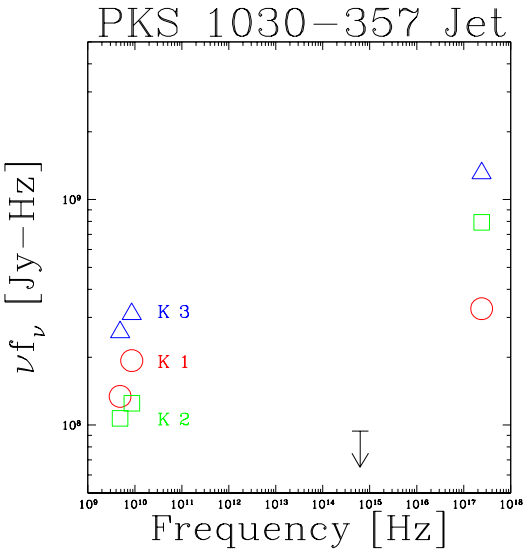

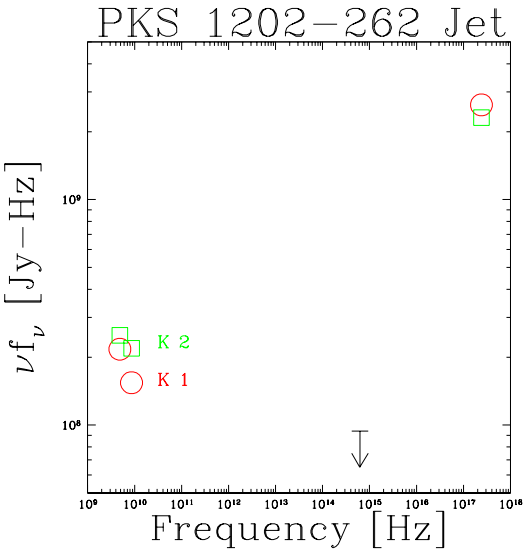

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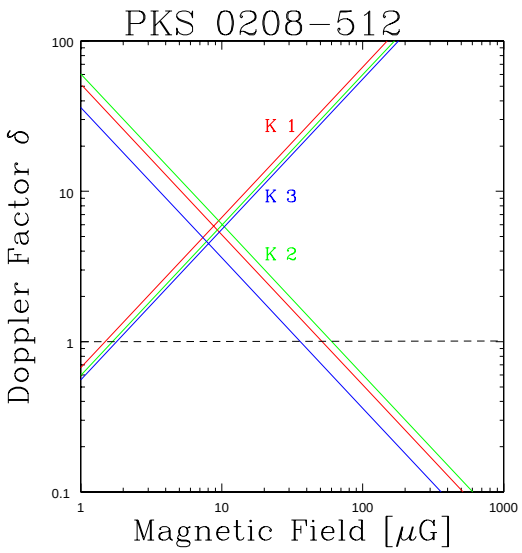

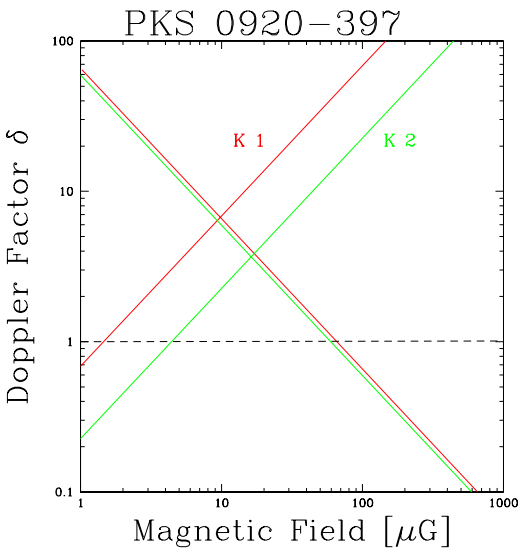

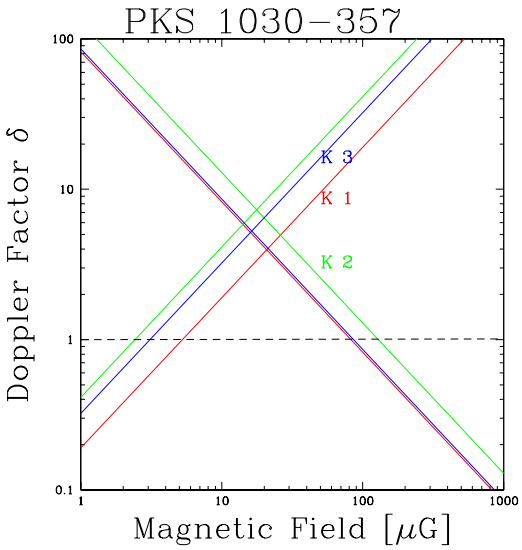

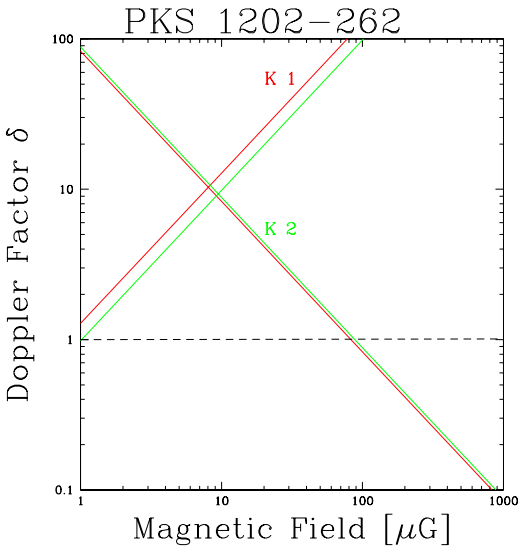

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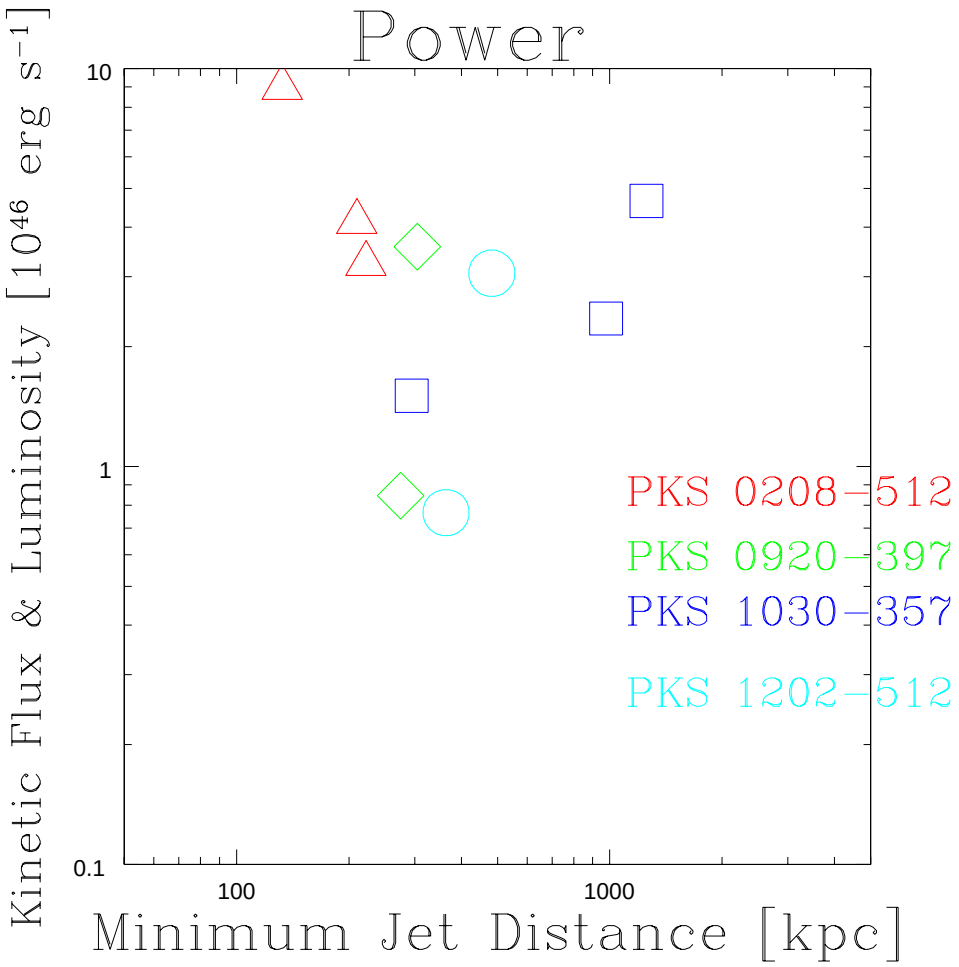
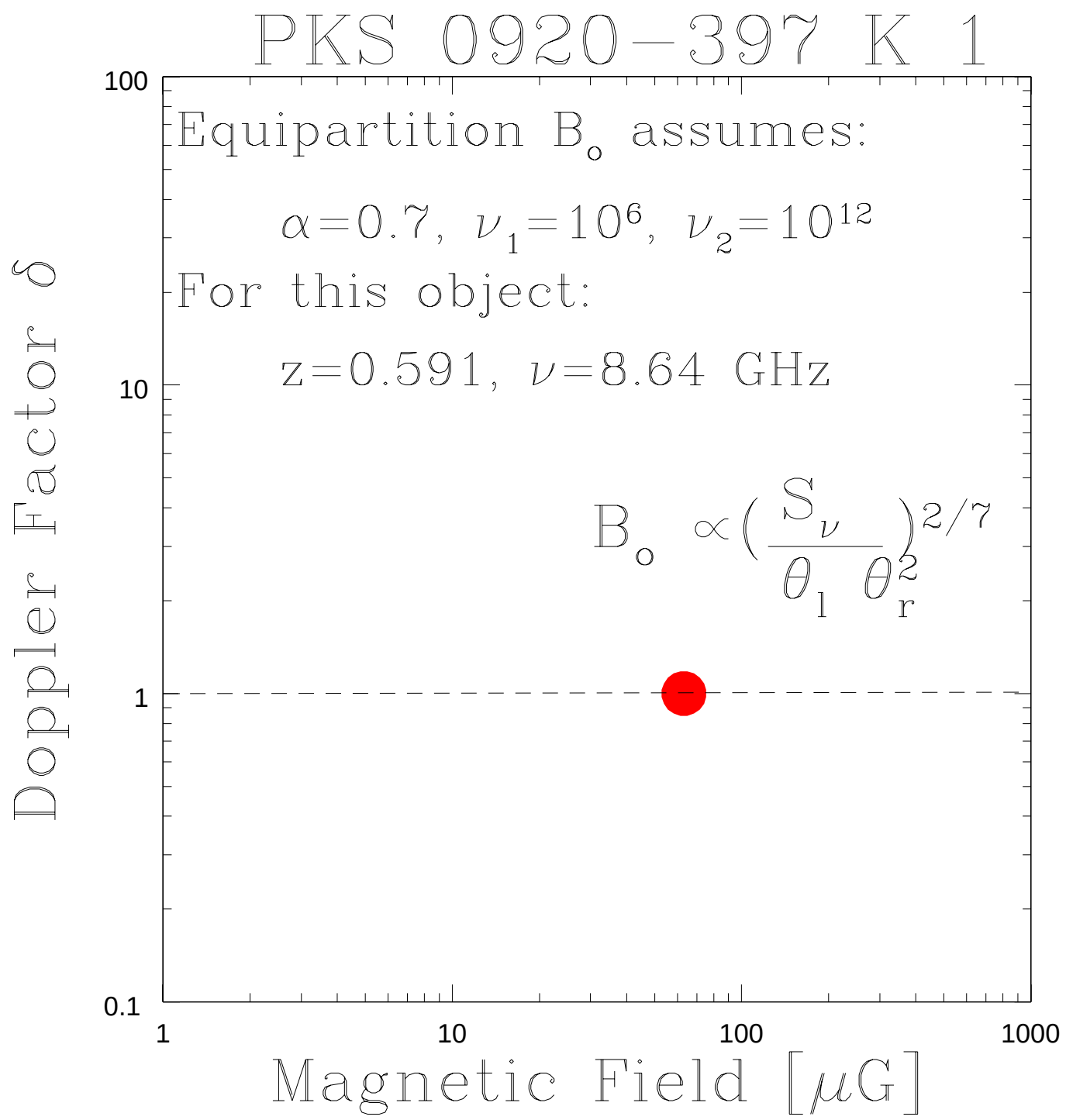
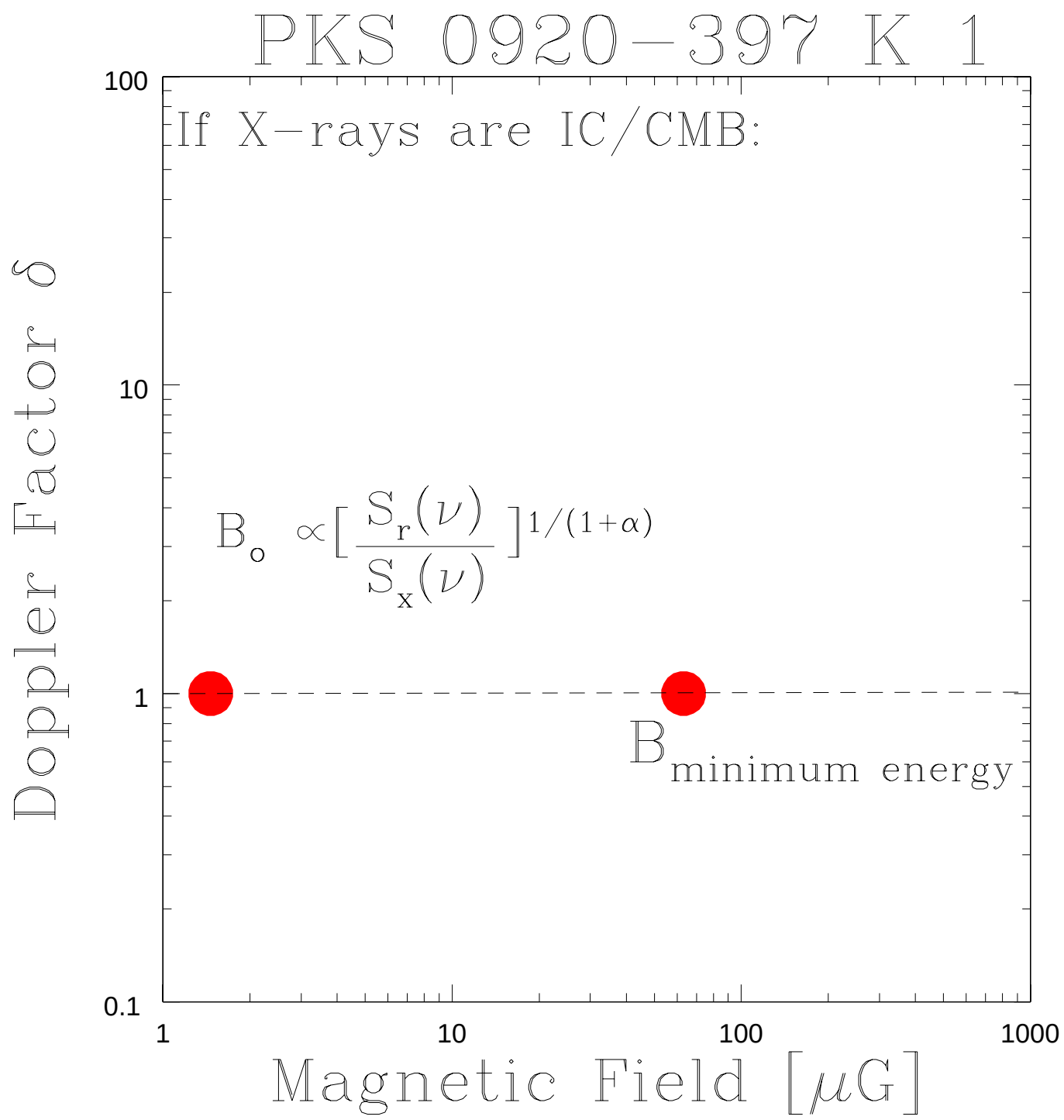
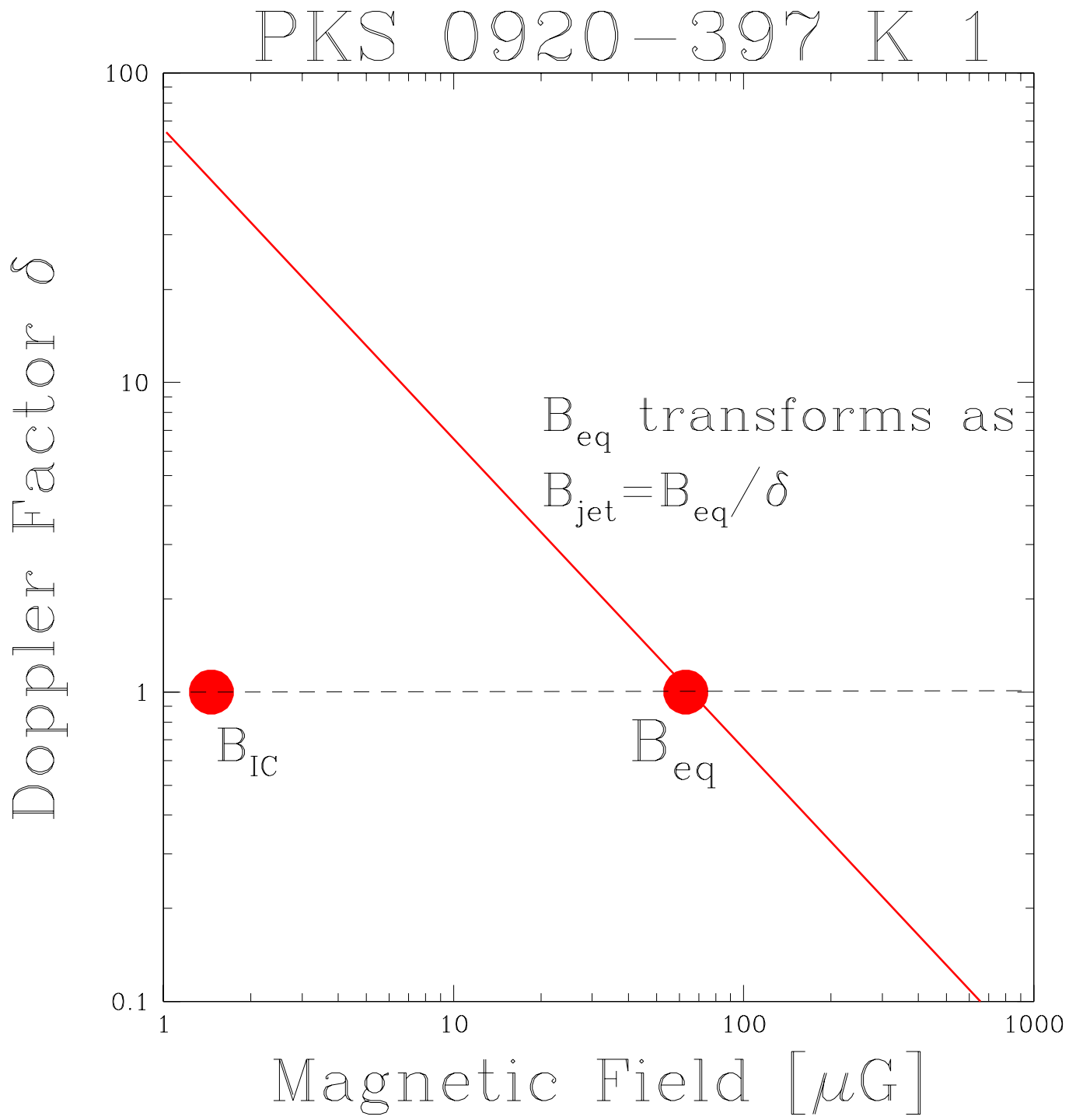
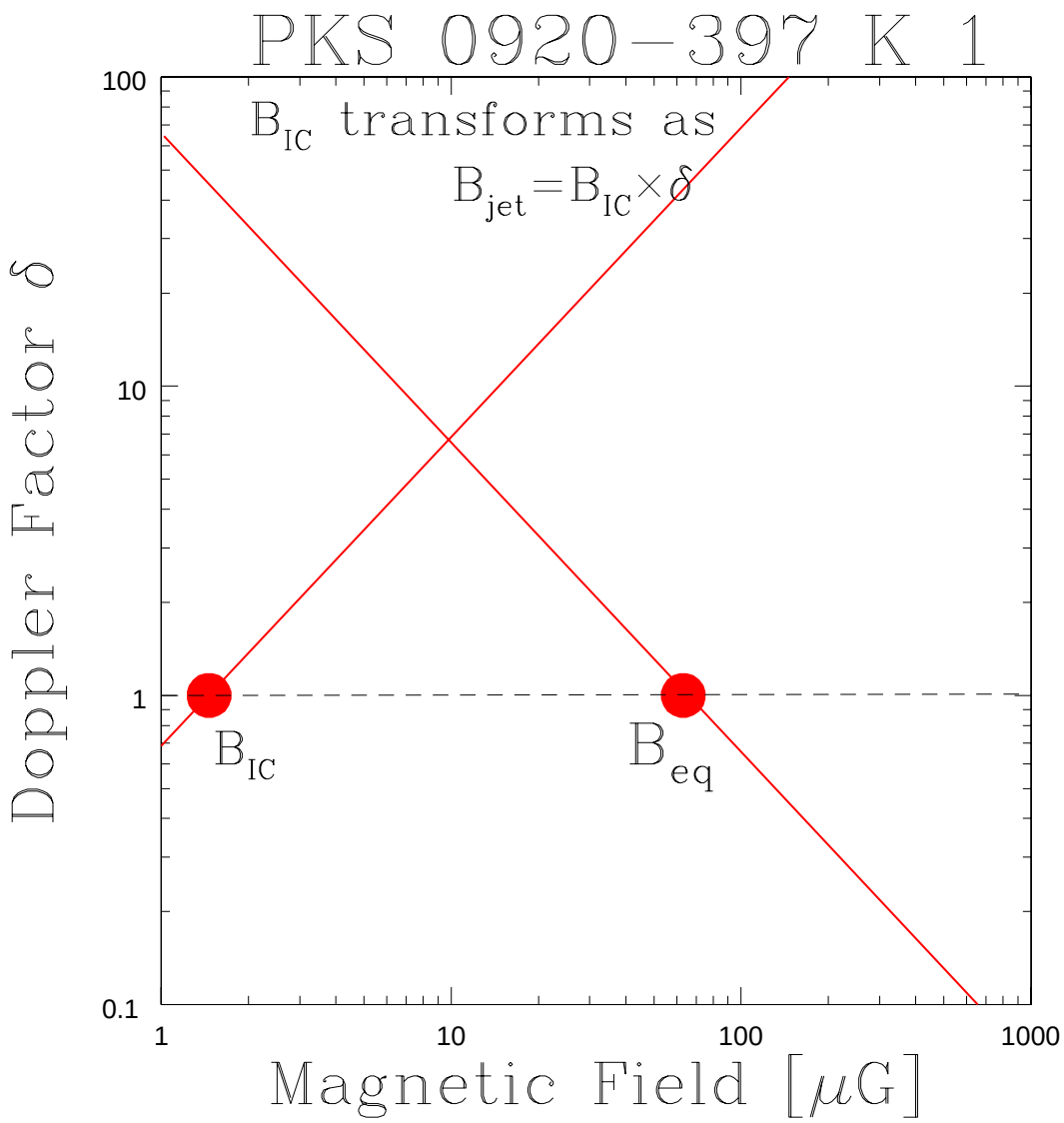
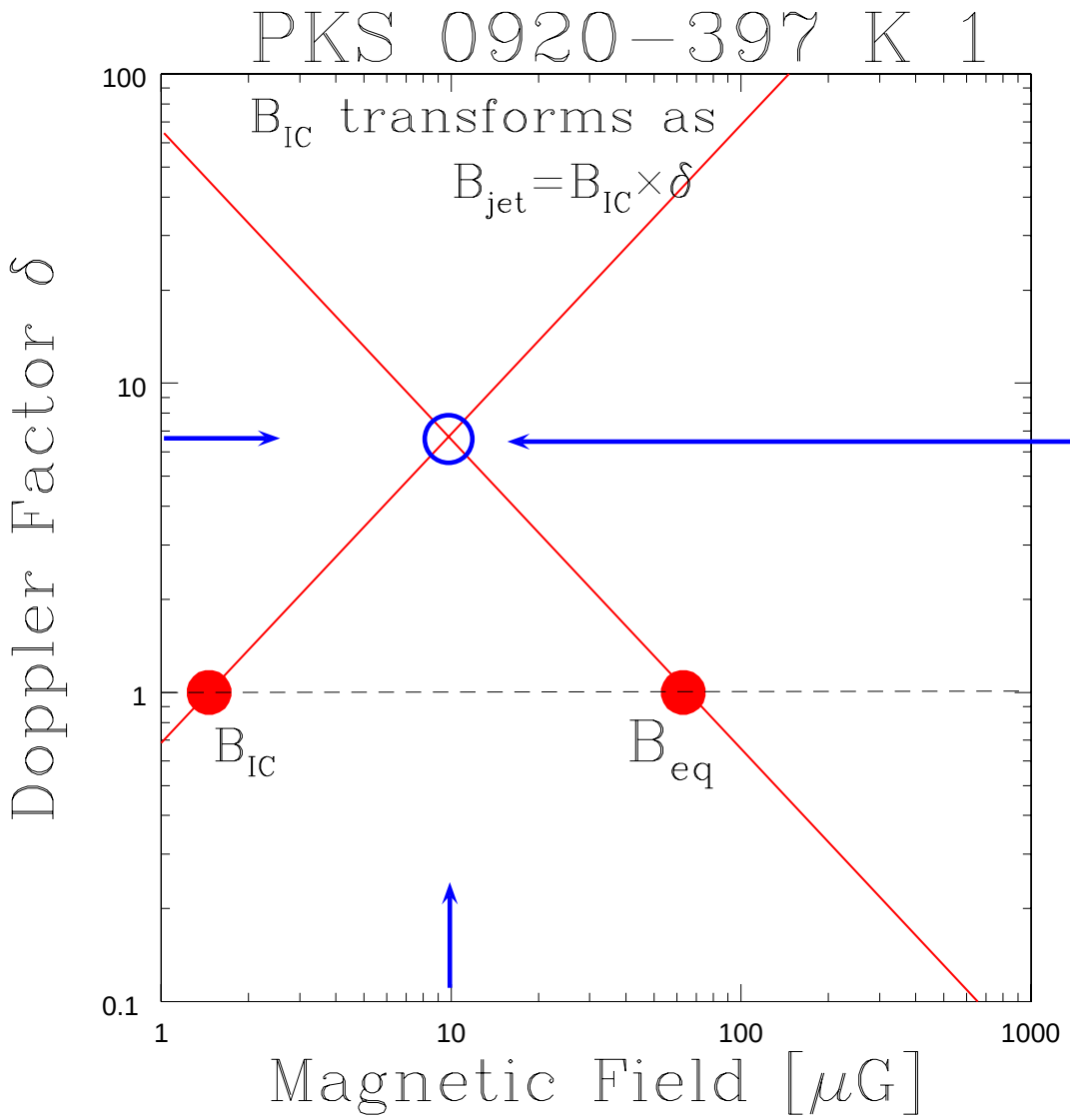



PKS 0920−397 K 1
Equipartition B$_o$ assumes:
α=0.7, ν_1=10^6, ν_2=10^{12}
For this object:
z=0.591, ν=8.64 GHz
$B_o \propto \left(\frac{S_\nu}{\theta_l\ \theta_r^2}\right)^{2/7}$
Doppler Factor δ
100
10
1
0.1
1
10
100
1000
Magnetic Field [μG]


PKS 0920−397 K 1
If X−rays are IC/CMB:
$B_o \propto \left[\frac{S_r(\nu)}{S_x(\nu)}\right]^{1/(1+\alpha)}$
$B_{\text{minimum energy}}$
Doppler Factor δ
Magnetic Field [μG]
100
10
1
0.1
1
10
100
1000


PKS 0920−397 K 1
100
10
1
0.1
1
10
100
1000
Doppler Factor δ
Magnetic Field [μG]
B_eq transforms as
B_jet=B_eq/δ
B_IC
B_eq


PKS 0920−397 K 1
B_IC transforms as
B_jet=B_IC×δ
Doppler Factor δ
Magnetic Field [μG]
B_IC
B_eq
100
10
1
0.1
1
10
100
1000



The intersection gives a solution for the magnetic field, B, in the rest frame, and for the apparent Doppler factor,

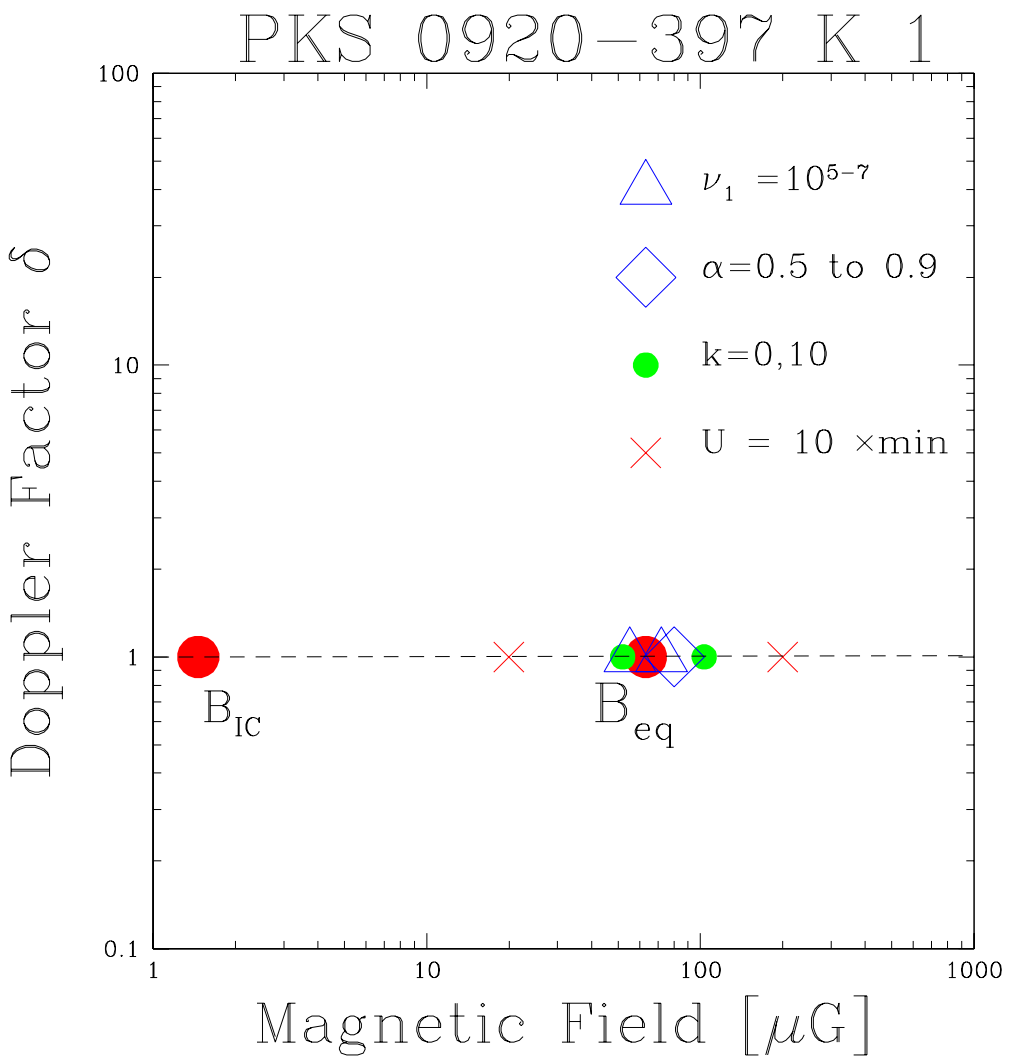
$\delta = (\Gamma(1 - \beta \cos(\theta))^{-1}$.

Here, B=9.6 μG and δ=6.6.

Uncertainties in the Magnetic Field Estimates

Uncertainties in the Magnetic Field Estimates

Equipartition



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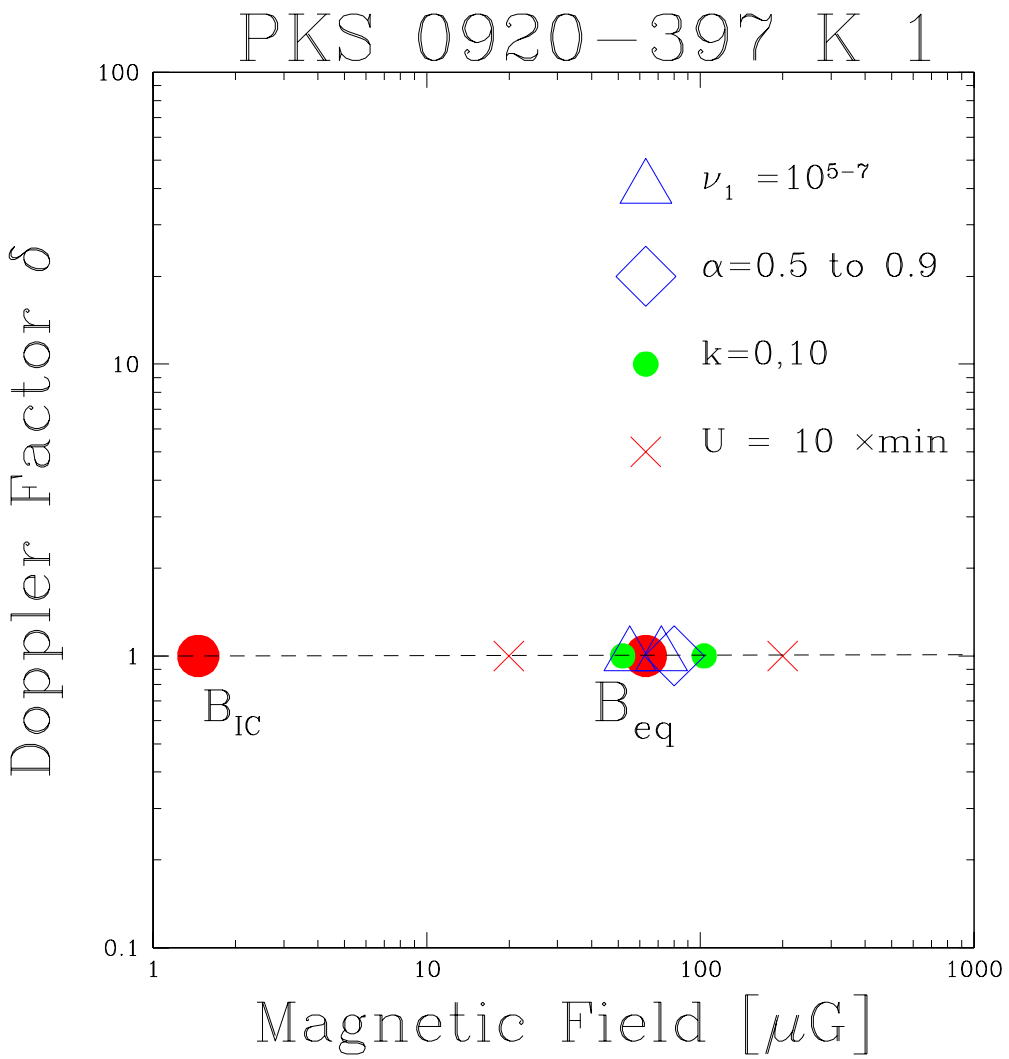
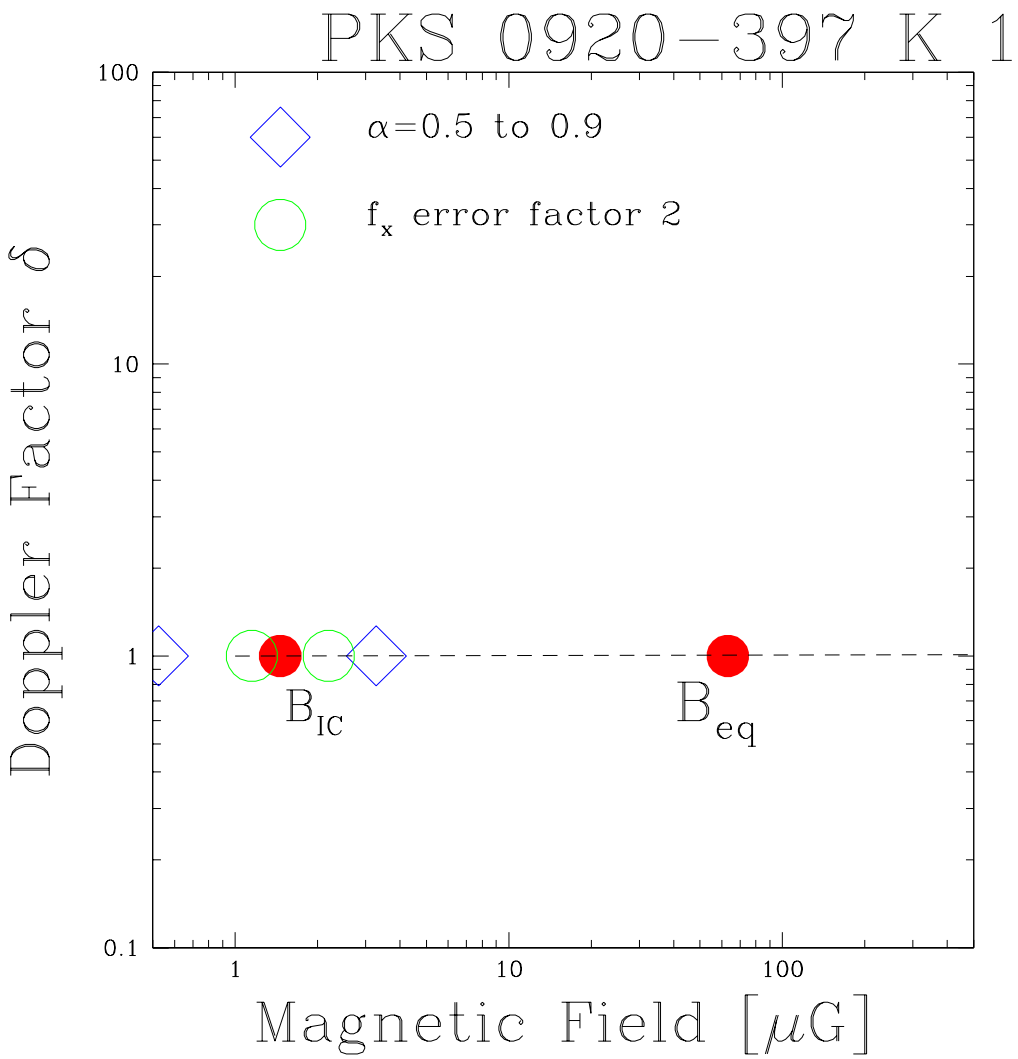
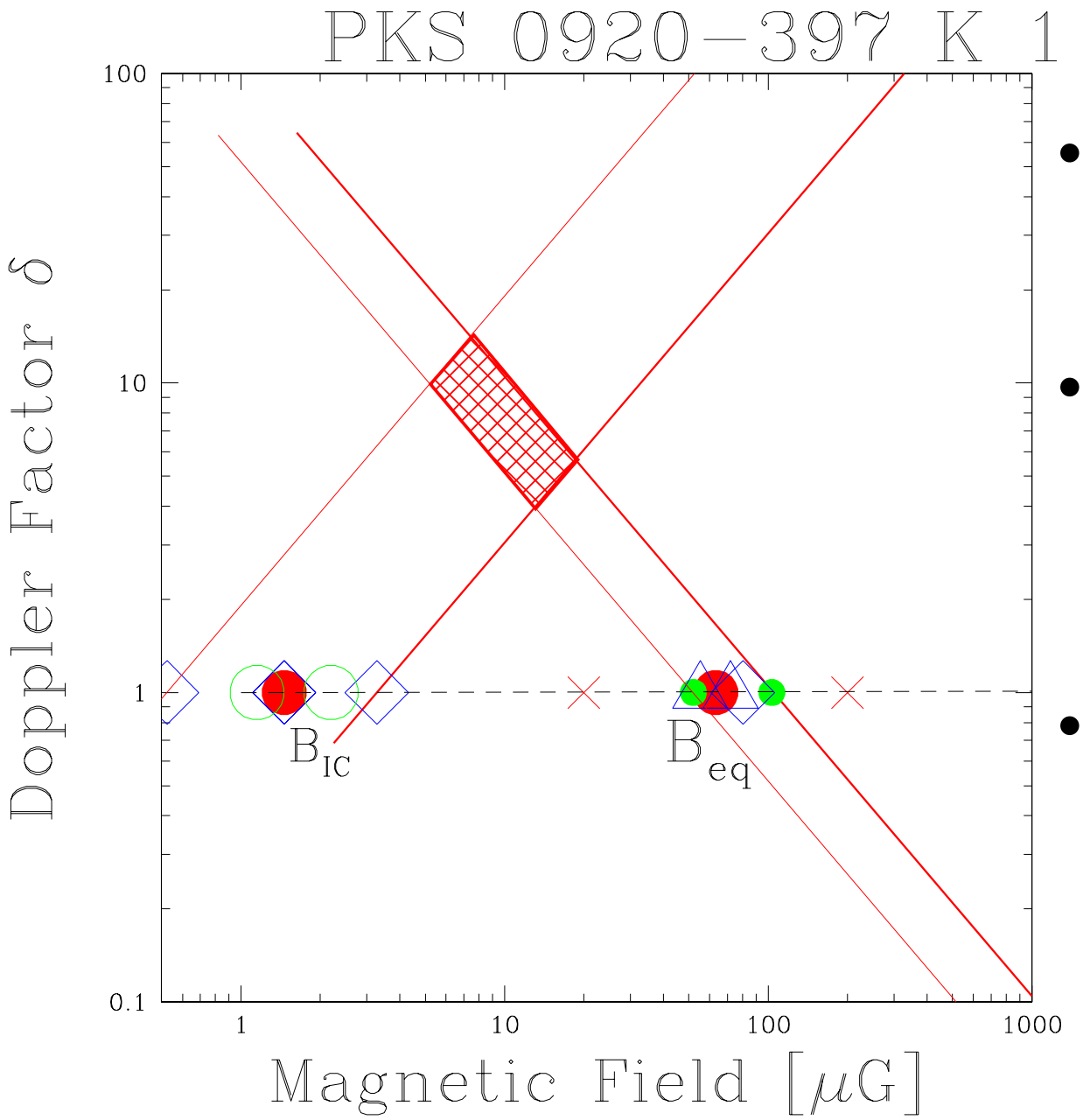
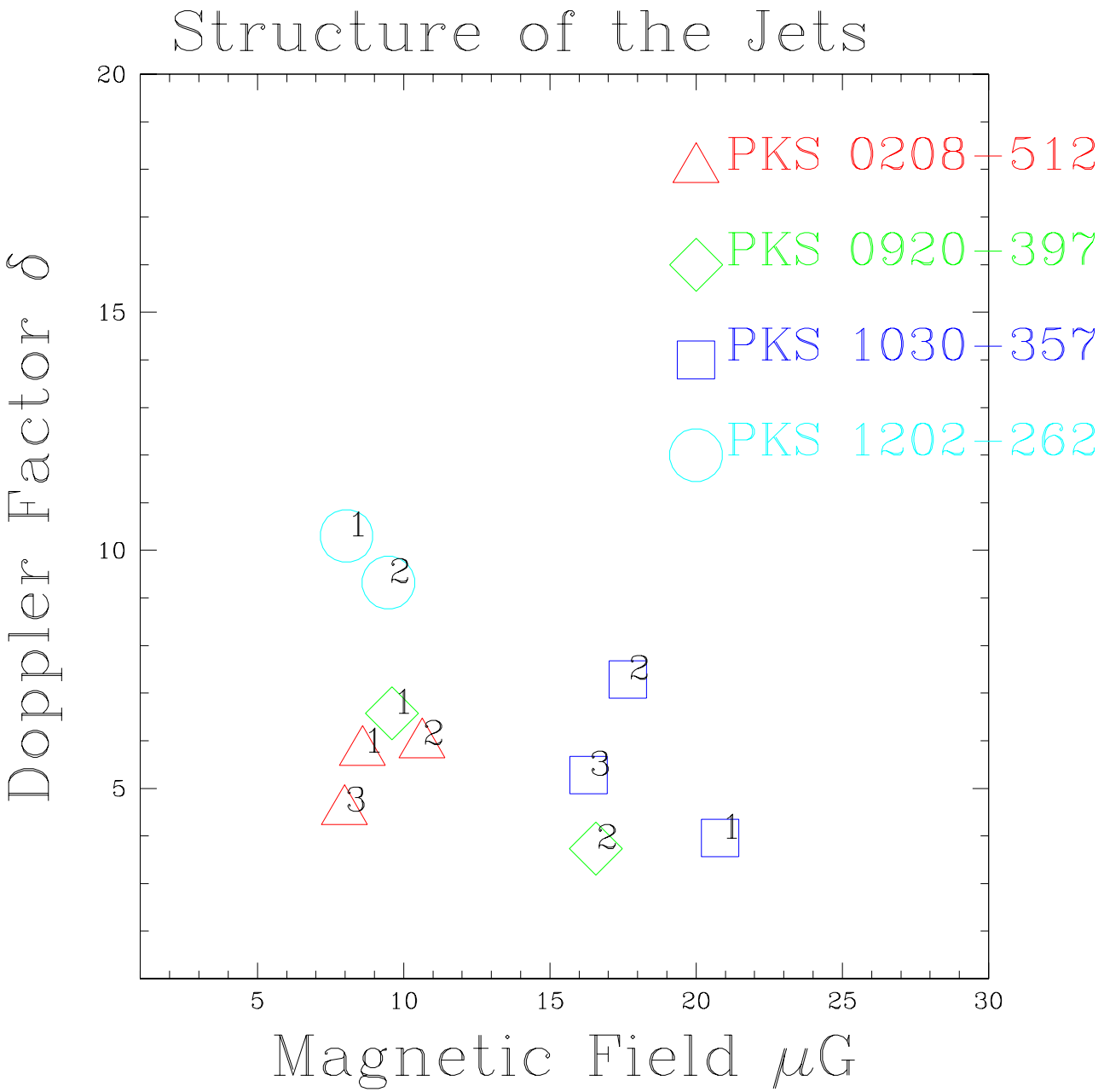


Inverse Compton

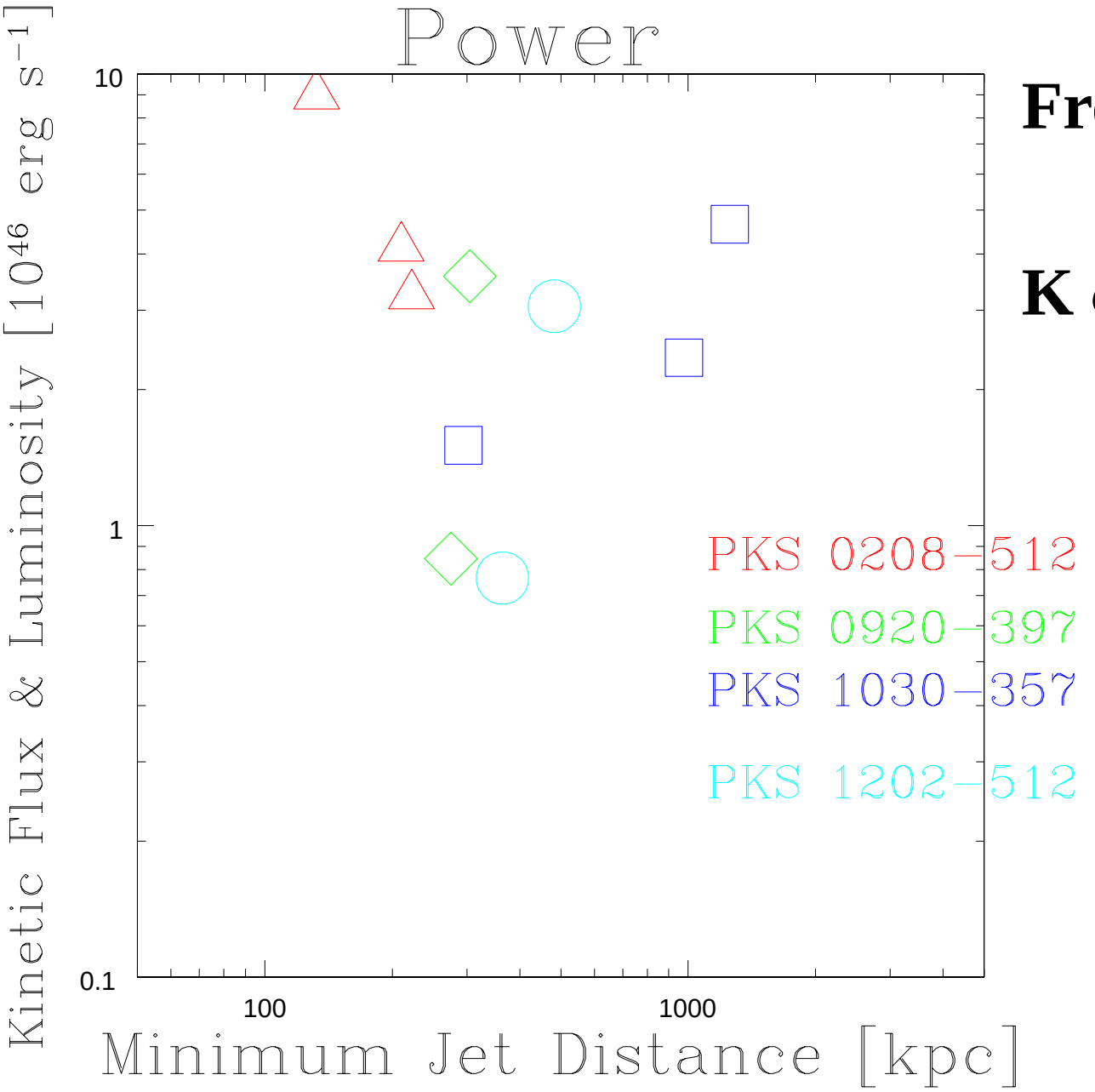




- **Determined B and δ within a factor of 2**
- **Can reduce IC region, depending on precision of radio spectral index**
- **Kinetic flux is $\propto (B\delta)^2$, for equipartition**


Structure of the Jets
Doppler Factor δ
Magnetic Field μG
PKS 0208−512
PKS 0920−397
PKS 1030−357
PKS 1202−262
20
15
10
5
5
10
15
20
25
30

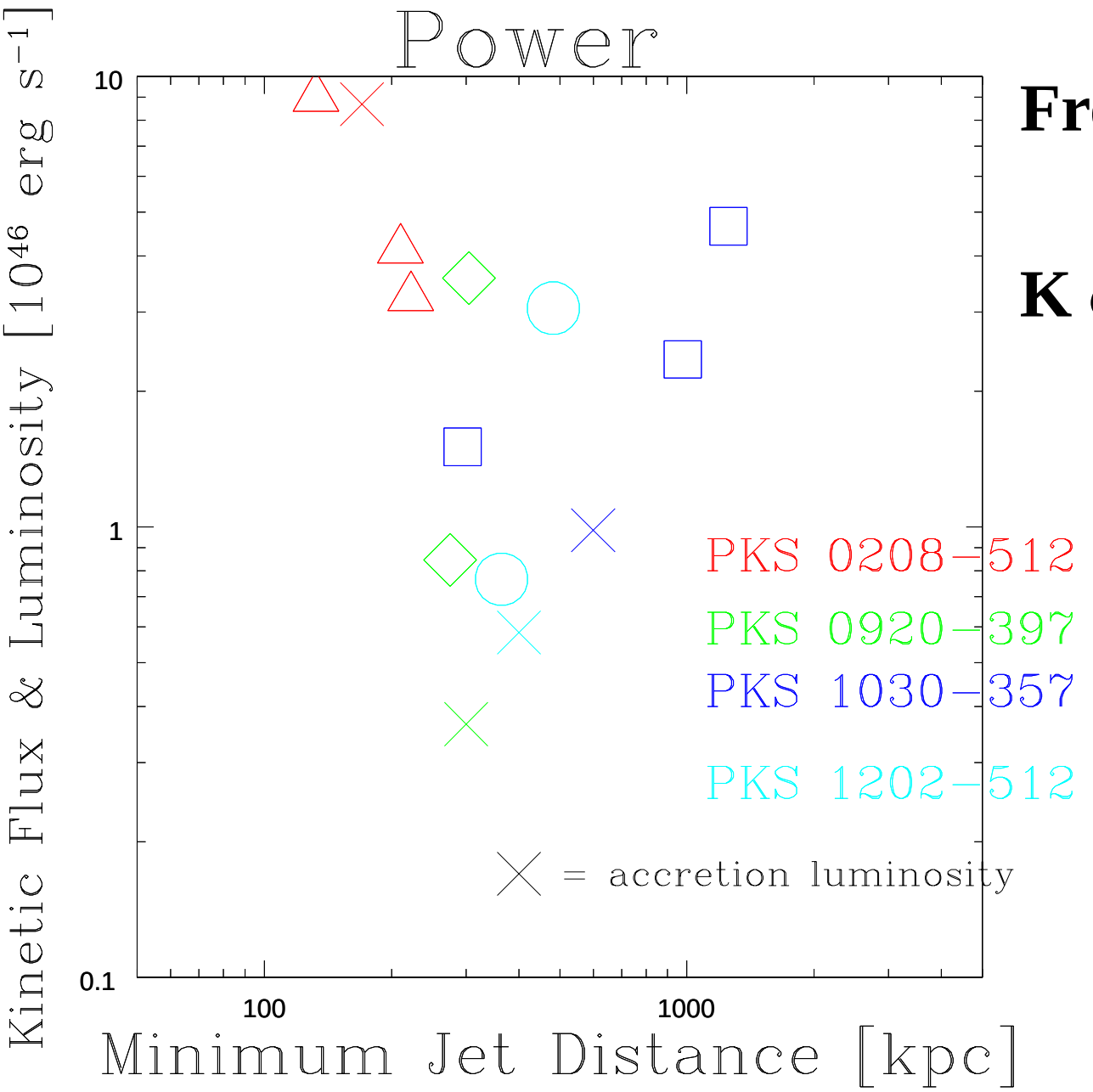
Kinetic Flux



From $K = \Gamma^2 \pi r^2 \beta c U$,

$K \propto \delta^2 \theta_r^2 (3 B^2/(8 \pi))$

Kinetic Flux



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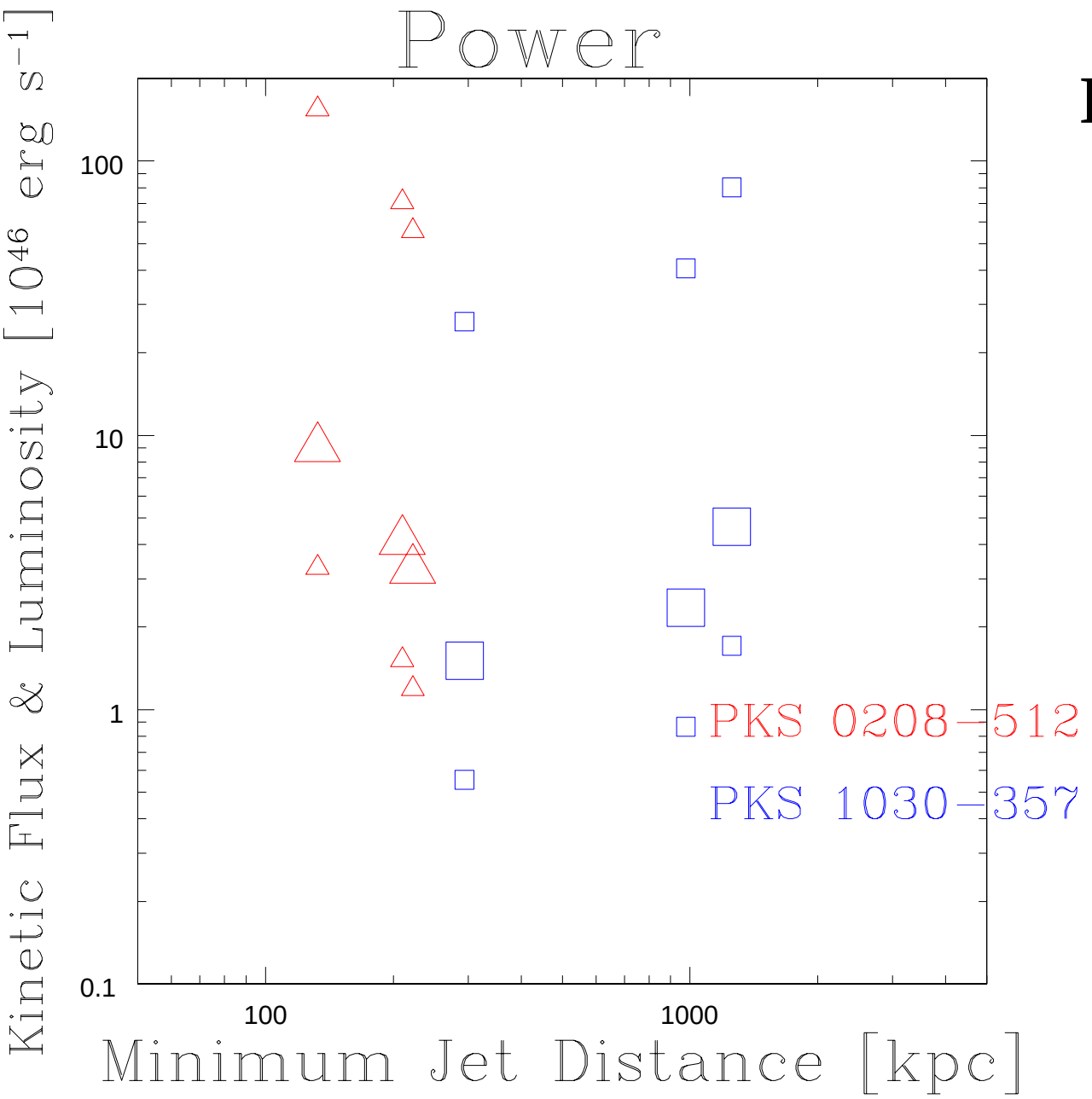
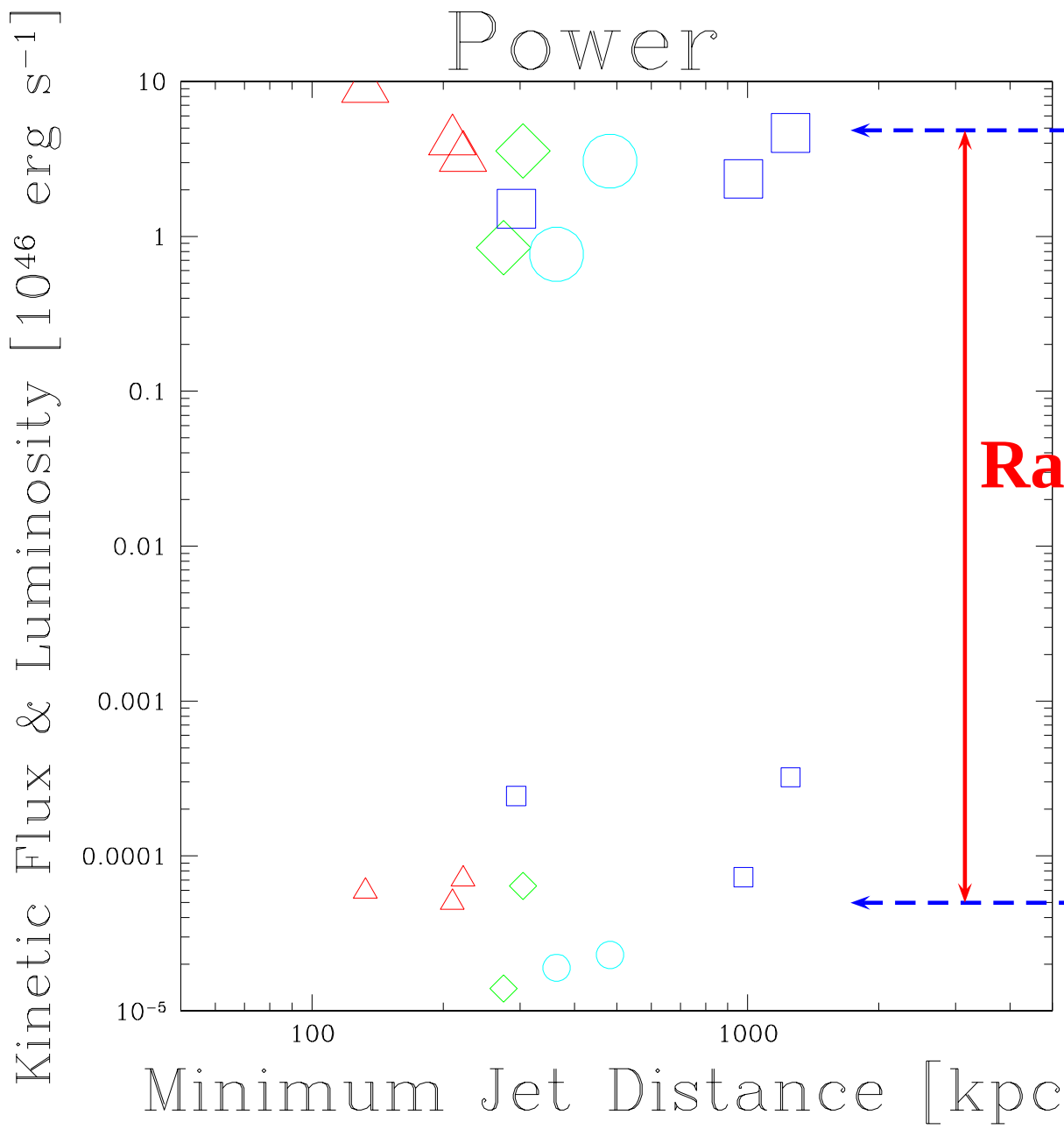


Kinetic Flux

Energy in Protons?

- **Large symbols assume $U_p = U_e$**
- **Lower symbols assume pure $e^{\pm}$ plasma**
- **Upper symbols assume cold protons, $n_p = n_e$, and $\langle \gamma \rangle_e = 183$**



Kinetic Flux

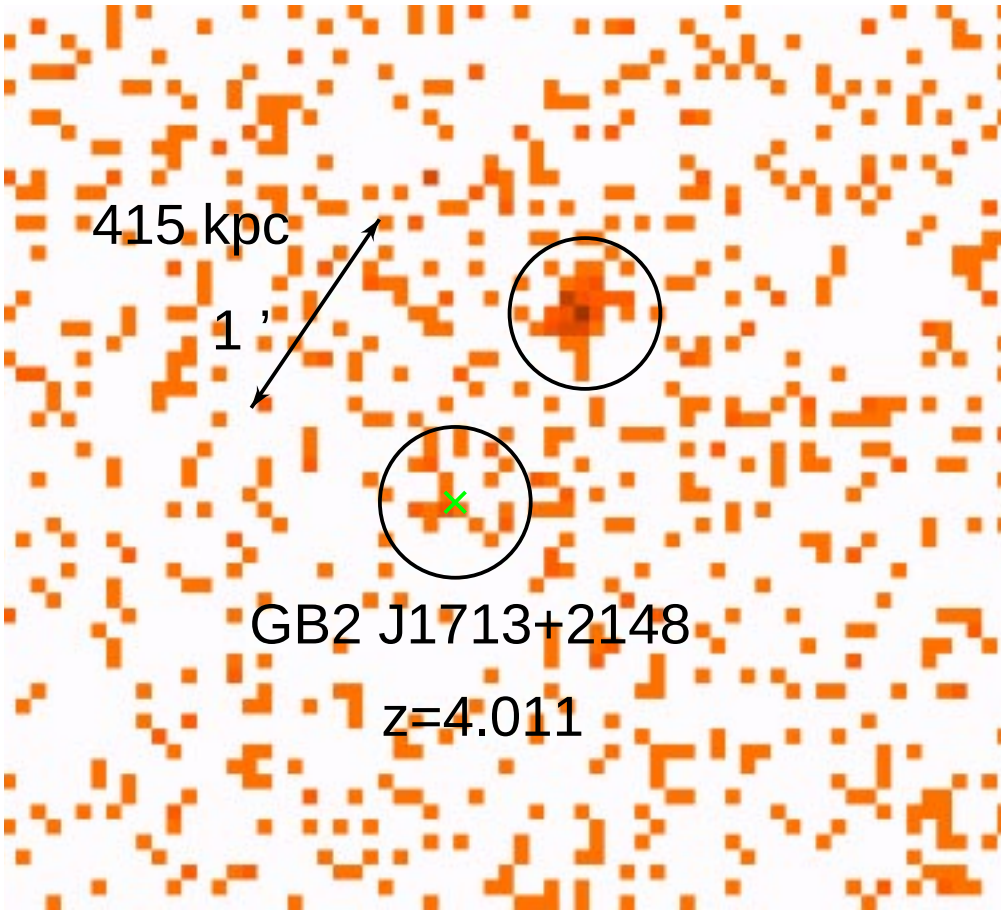
Radiative Inefficiency
$\approx 10^{-5}$

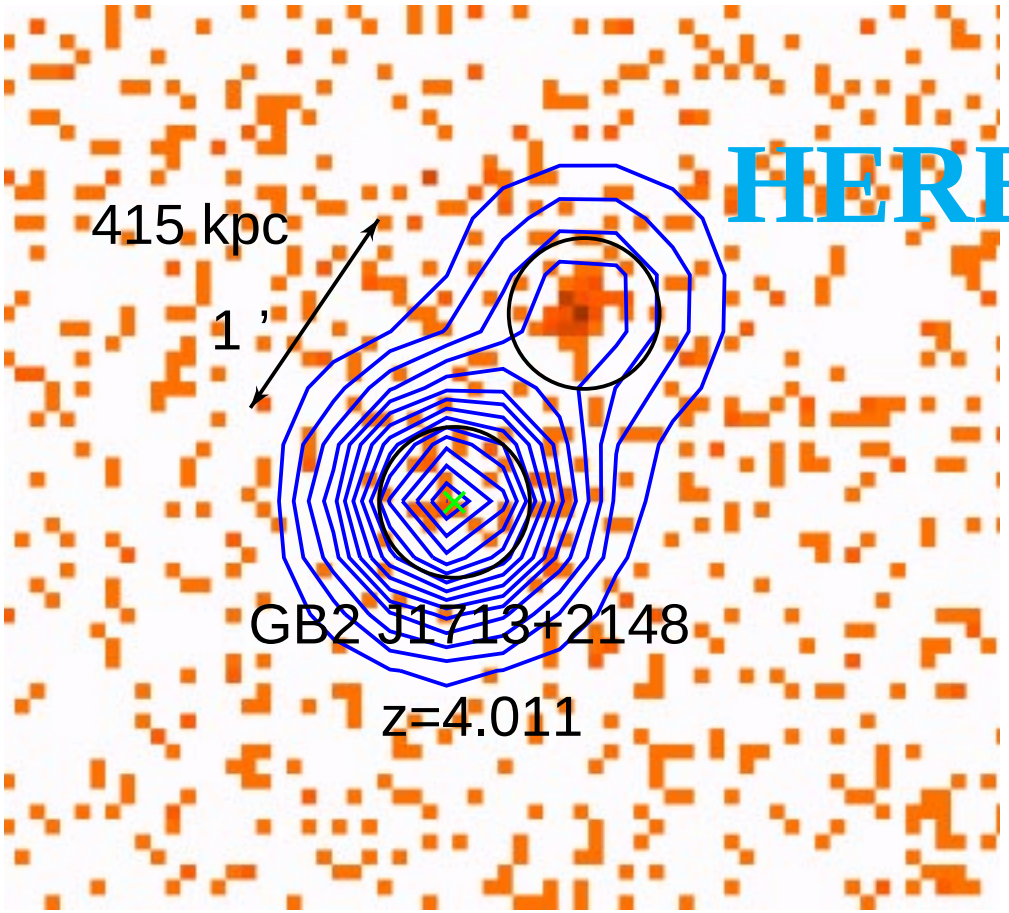
Radiative luminosity

Implications of the X-Ray Jets

- **Eddington Luminosity might not limit Accretion Rate**
- **Jets may Power Cluster Cavities – Stop Cooling Flows**
- **IC/CMB X-ray jets Maintain Constant Surface Brightness vs. z. We will detect them at Arbitrarily Large Redshift.**

Where ARE the bright X-ray Jets at High Redshift?





HERE!

Gurvits et al. 2003

Where ARE the bright X-ray Jets at High Redshift?

HERE!

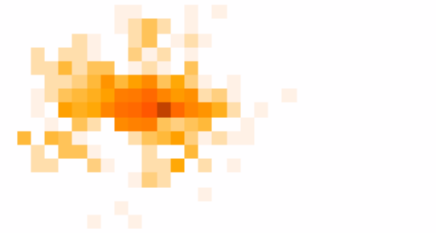
Siemiginowska et al. 2003

There Should Be Radio Quiet X-Ray Jets!

- **1 keV X-rays produced by $\gamma \approx 1000/\Gamma$**
- **$\nu = 4.2 \times 10^{-6} \gamma^2$ H[μG] $\approx$ 10 MHz**

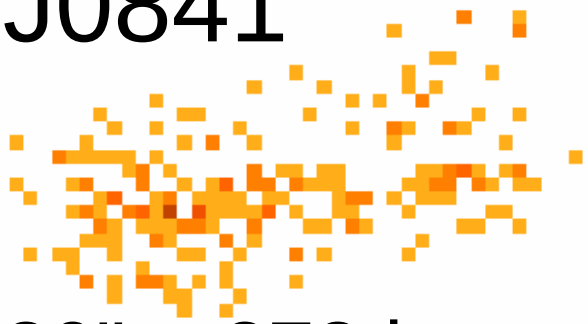
A Radio Quiet X-Ray Jet?

EMSS 0841+1314



30"

J0841



30" = 273 kpc

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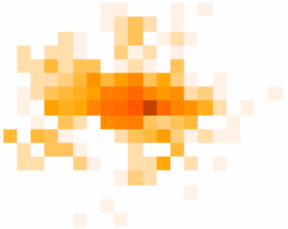

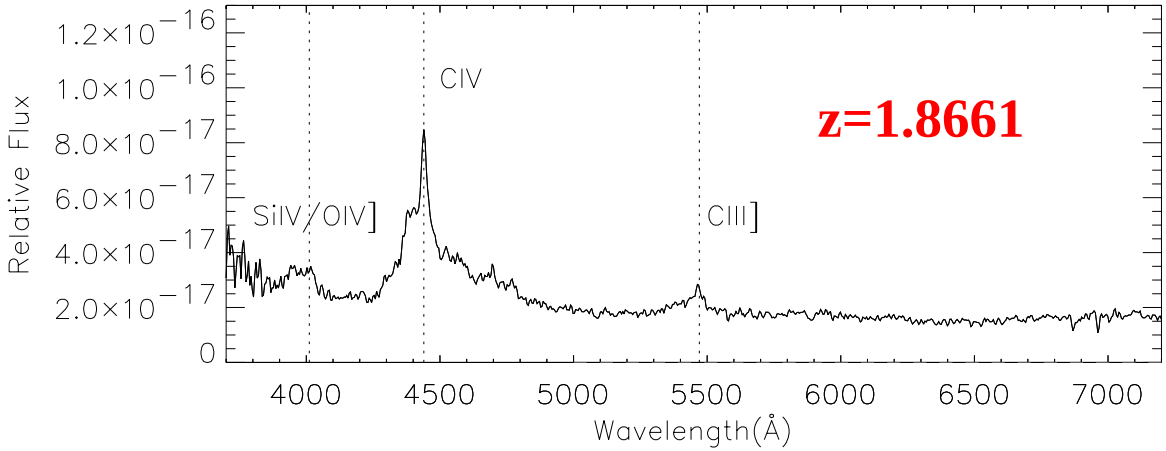

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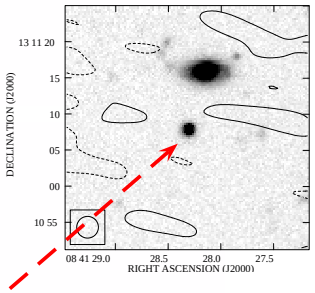

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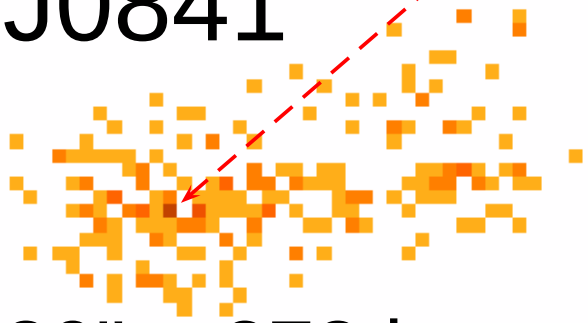

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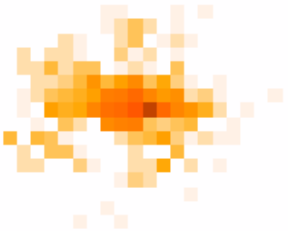

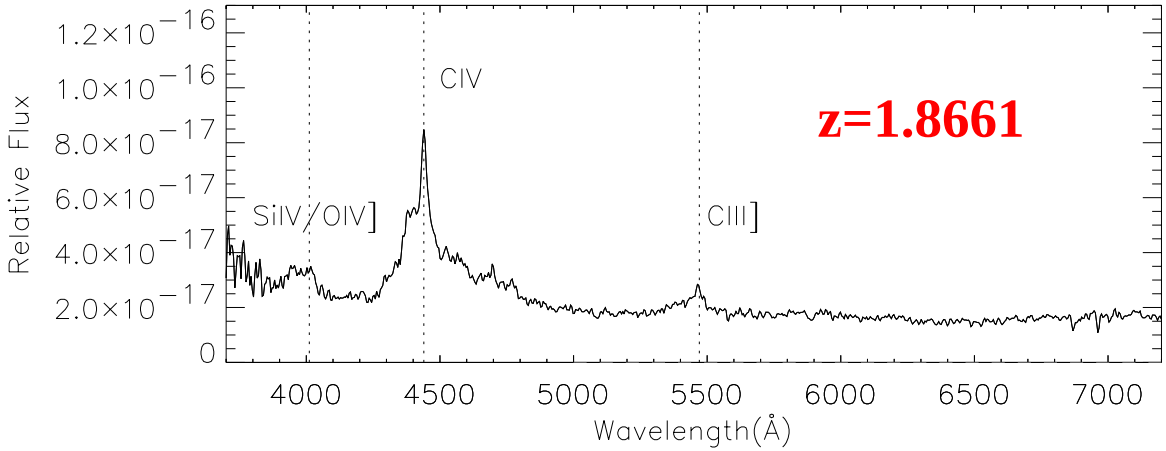

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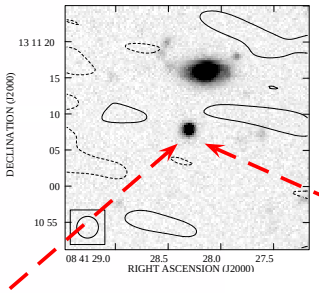

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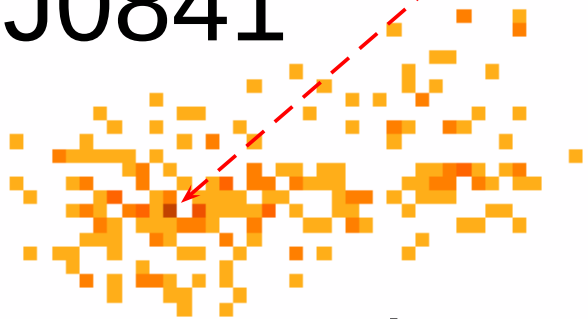

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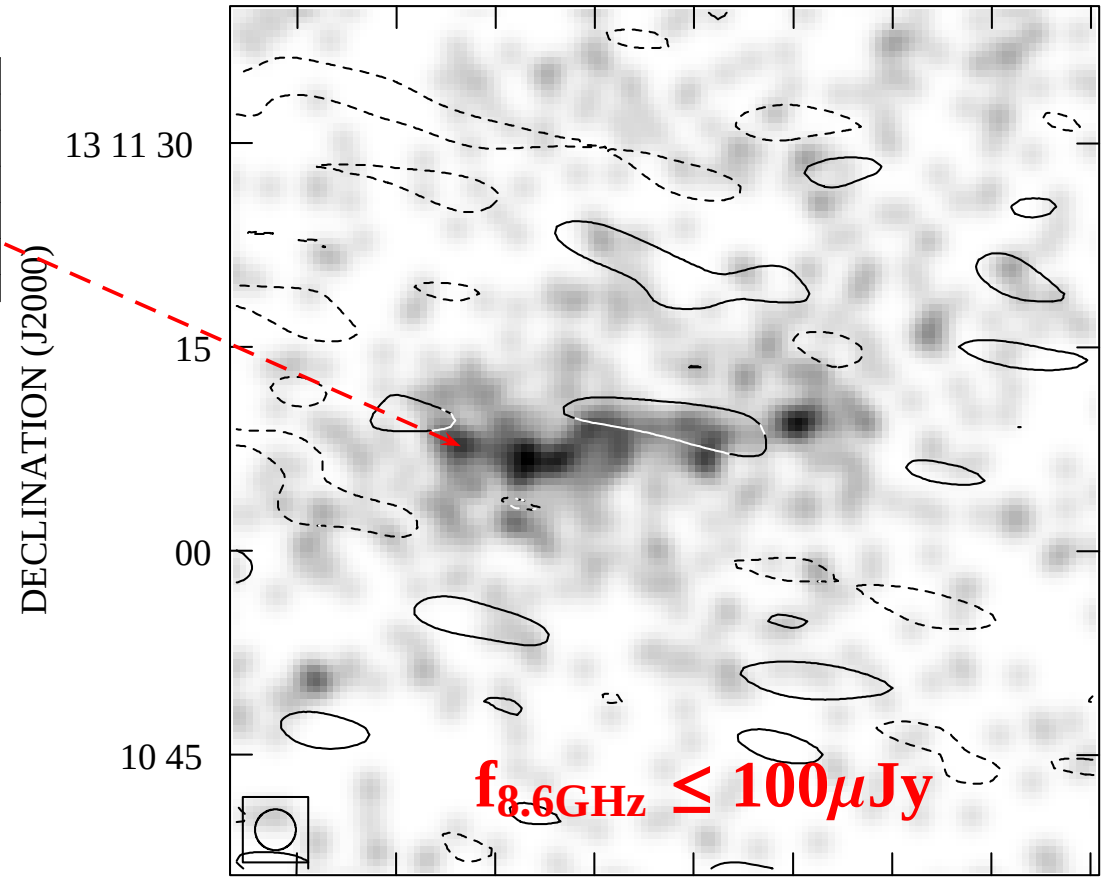

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2. **Transport Energy Very Efficiently – $L_{jet} / K_{jet} \lesssim 10^{-5}$**

We Predict:

3. **X-ray Jets become more prominent at large redshift**